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Effect of plant roots on soil anti-scouribility of topsoil during concentrated flow

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ABSTRACT

Plant roots increase aggregate stability of soil both hydrologically and mechanically and increase anti-scourbility of the top soil. In the present study the quantification of the impact of roots properties (root density, RD; root length density, RLD and root surface area density, RSAD) on anti-scourbility was attempted for better understanding of the effectiveness of indigenous plants to control soil erosion during concentrated flow. Eighteen top soil samples were collected with a representation of varied grass cover from Rangamati experimental station, Paschim Medinipore, West Bengal of lateritic environment. Samples are collected in metal boxes and allowed to have similar moisture content before the experiment. Flume experiment was run with flow rate of 9 to 10 lit/min on the erosion pan set at a gradient ranging from 15 to 45 degree. Each sample was experiment to flow for 1.5 min during which runoff water and detached sediment was collected at 15 sec interval. Roots are separated from the soil samples by wet hand wash with sprinkling water after the experiment. Root density, root length density and root surface area density were calculated with proper techniques. Rate of soil detachment ranges from 5 to 20 g/lit and that has strong relation with root properties. The results indicated that a significant exponential growth relationship between root properties (RD, RLD and RSAD) and anti-scourbility (AS) was established using origin 8.0 programme. Value of correlation of determination is more than 0.90 ($p<0.01$) in all the cases, that shows strong possibility of reducing soil erosion by increasing root properties of indigenous plants grown naturally in the area under study.

Keyword: *Concentrated flow, Anti-scourbility, Root density, Root length density, Root surface area density*

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Introduction

The soil resistance to erosion in concentrated flow is an important factor for predicting rill and gully (ephemeral) erosion rates (Knapen et al., 2007b). Concentrated flow erosion is defined as the detachment and displacement of soil particles by channelised water flow, resulting in the development of rills and ephemeral gullies (Gyssels and Poesen 2003). Soil erosion through rill-gully is of great concern in the lateritic badland topography of western part of West Bengal in India; because every year about 1.04 lakh ha area is affected by rill-gullies (Sharda et al., 2007). Soil erosion is a serious problem in most agricultural and fallow lands worldwide. Tropical badlands are affected concentrated flow erosion along intensively spaced rills and gullies. Traditionally, soil erosion by water has been considered the cause of the loss of plant nutrients, as well as productivity (Zhou and Shangguan, 2005). Numerous studies have been conducted to evaluate the effect of vegetative cover on soil erosion. The results indicated that soil erosion decreased with increasing vegetation cover (Li, 1993; Zhang et al., 2003; Wei et al., 2006; Zheng, 2006; Zhou et al., 2006). However, limited research has been conducted regarding the influence of plants roots on soil erosion and the reduction of runoff (Gyssels et al., 2005; de Baets et al., 2006). In the present work attempts have been made to understand and quantify the impact of roots of indigenous plant grown naturally on lateritic tropical environment to increase anti-scourbility of soil.

Mechanics of plant roots on soil erosion

Roots reduce soil erosion by binding the soil particles at the ground surface and reducing surface runoff velocity (Greenway 1987). The soil adjacent to the roots is affected both hydrologically and mechanically, in terms of aggregate stability (Wang et al., 2011), infiltration capacity, soil bulk density, soil texture, organic and chemical content and shear strength, all of these being important determinants for soil erodibility (Ame´zketa 1999; Li et al. 1992; Morgan 2005; de Baets et al., 2007). The mechanics of how plant roots reinforce the soil are two-fold. First, roots and root remnants physically bind soil particles and in this way form mechanical barriers for soil and water movement (Tengbeh, 1993).

Major controlling parameters of the mechanical influence of roots are: diameter, degree of bifurcation, appearance of root hairs, friction between root and soil and, obviously, root network distribution (Abe and Ziemer, 1991). Shallow interlocking root networks can substantially contribute to mechanical reinforcement of soils, acting as an anchored net of densely interwoven roots (Sidle et al., 1985; Preston and Crozier, 1999). Dense root mats carpet the ground and provide substantial soil cohesion, which ultimately limits erosion by overland flow (Prosser et al., 1995; Sidorchuk and Grigorev, 1998). Moreover, living and dead root systems can provide subsurface water flow pathways by creating bio-pores and thus reducing the amount of erosive overland flow. Secondly, roots and root remnants excrete binding agents and form a food source for micro-organisms that in turn produce other organic bindings (Reid and Goss, 1987). These bindings increase the amount of stable soil aggregates in the long term and thus reduce soil erodibility (Hartman and De Boodt, 1974).

In recent years, research on root– soil interaction has increased considerably. Although quantitative data on the effects of roots mainly result from research on slope stability, some experimental studies investigate the effects of plant roots on water erosion processes. These studies often concentrate on roots from crops, whereas root properties and root effects of native vegetation are much less studied. Studies investigating the impact of roots on the resistance of the topsoil to concentrated flow erosion generally use root density (RD, kg m-3) or root length density (RLD, km m-3) as a root parameter to predict the water erosion reducing effect (Gyssels et al. 2005). Zhou and Shangguan (2005) agree with Li et al. (1991) that RLD is a good parameter for expressing the root–soil contact area, but stated that the root effect cannot be precisely predicted if only the number of roots <1 mm is used. Zhou and Shangguan (2005) stated that root diameter distribution has to be taken into account as well when predicting the erosion reduction by roots during concentrated flow and therefore propose to use root surface area density (RSAD, cm2 cm3) for predicting the soil anti- scourability. De Baets et al. (2007) show that root diameter is an important variable in explaining relative soil detachment rates as the erosion-reducing effect of RD decreases with increasing root diameter.

There are numerous reports on the profound effects that living plant roots have on the formation of aggregate structure and maintaining soil stability ((Reid & Goss, 1980; Reid & Goss, 1981); (Habib et al., 1990); (Dexter, 1991)). Mamo & Bubenzer, 2001a, indicated that concentrated flow erodibility decreased over time with increasing root length density. Gyssels et al., 2005 and Gyssels & Poesen, 2003; observed an exponential decline in relative soil loss by concentrated flow erosion with increasing root density. However, root properties (RD, RLD) must be considered in any investigation of the effects of root on soil anti-scouribility. We hypothesized that a topsoil anti-scouribility and root density would fairly account for soil erodibility in concentrated flow. In this study the effect of fine-branched root systems on the resistance of topsoils to concentrated flow erosion are quantify through flume experiment and established equations for predicting the erosion-reducing potential of indigenous plant root systems during concentrated flow.

Materials and Methods

Study site, soil sample collection and preparation

Undisturbed eighteen one topsoil samples for the present study were taken from grassland, fallow land and partially cover with vegetation lying in the Rangamati experiment station (22°24' N and 87°17' E) for the lateritic environment of West Bengal, India. The grass that was used is a mixture of the following species: 23% of Andropogon aciculate (Poaceae), 40% of Eragrostis cynosuroides (Poaceae), 17% of Panicum maxima (Poaceae), and 20% of Saccharum munja (Poaceae). The climate is tropical type with prolonged dry season experiencing a mean annual rainfall of 1850 mm and a mean temperature of 28.4 °C. The region has a typical undulating lateritic landforms and topography, with its altitude ranging between 20 and 85 m m.s.l. The soil is sandy loam with sand, silt, and clay contents of 56%, 24%, and 20% respectively and bulk density ranges from 0.82 to1.43 (g/cm3). For sampling, the metal boxes (0.35 m long, 0.09 m wide and 0.08 m deep) were driven into the soil using a hammer. To protect the top of the metal box, a wooden plank was placed on the top during the hampering.

After sampling, the above ground biomass (i.e. stem) was clipped up to the level of soil surface and the samples were placed in a container with a constant water level 3.5 cm below the soil surface to allow for slow capillary rise for 8 hours, in order to obtain similar soil moisture contents for all samples. In this process, all samples were stored in a normal room temperature (20-25 °C).Twelve hours before the experiments, the soil samples were taken out of water to drain.

Concentrated flow simulation and measurements of anti-scourbility of soil

Laboratory experiments on simulated concentrated flow were conducted with a flume similar to the description by Wang et al., 2011 (Fig. 1; length= 1.82 m, width= 0.094 m). The flume contained an opening at its base, equaling the size of the metal sample box (length =35 cm, depth = 9 cm, width = 8 cm), so that the soil surface of the sample was at the same level of the flume surface. The soil erosion pans were set at a slope gradient ranging from 15 to 45°, with flow rate of 9 to 10L/min. For sediment concentration measurement, runoff water and detached sediment are collected 10 times during the experiment run (each experimental run lasts 1.50 minute) in 210 buckets at outlet of the flume. After the simulated concentrated flow, all the buckets were weighed and the sediment-laden water was allowed to stand until suspended sediments settled in them. Clear water was siphoned off, and the sediments were transferred to glass and oven-dried at 105°C for 8 h and weighed. Soil anti-scouribility Index (ASI; L/g) was expressed by soil erodibility in the following formula:

$$ASI = \frac{f.t}{W} \quad \text{........................(1)}$$

Where f is flow rate (in L/min), t is the washing time (min), and W is the weight of the oven-dried sediment (g). The higher soil AS, the lower the soil erodibility.

Measurement of Root properties

After each experiment, roots were separated from the soil by wet hand washing method (Schuurman and Goedewaagen, 1965) and the root samples were washed and sieved using a 0.5mm sieve, by sprinkling water at low water pressure (De Baets et al. 2006). Then the root density properties of each sample were measured manually flowing:

Root density (RD) is ratio of root mass and volume of soil sample.

$$RD = \frac{M_D}{V} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where MD is dry living root mass (g) and V is volume of the sample box (cm3)

Root length density (RLD) is the total length of the roots divided by the volume of the root-permeated soil sample (Smit et al., 2000).

$$RLD = \frac{L_R}{V} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where LR is length of the living roots (cm)

Root Surface Area Density (RSAD) is the total surface of contact of roots with sample soil is calculated as following (de Baets et al.2007)

$$RSAD = N\frac{D.RL}{2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where, N is number of roots, D is mean root diameter and RL is mean root length.

Analysis methods

All analyses were performed using MS Excel and Origin-8 program. Significant differences among treatments for anti-scourbiity and plant root properties were determined using the LSD (least significant difference) procedure for a multiple range test at the 0.01 significance level. The relationships between anti-scourbiity and RD, RLD and RSD were analyzed by a non-linear regression method. The regression results were evaluated by the coefficient of determination.

Fig-1 *Illustration of the topsoil area occupied by fine roots(indicated by arrows) for plants with fine-branched root systems (above) and Hydraulic flume used to measure detachment rates from root permeated topsoil samples (bellow)*

Results and Discussion

Effect of Root properties on soil anti-scourbility

The value of the intensified soil anti-scouribility (AS; L/g) for describing the effect of roots on soil anti-scouribility was calculated by subtracting the anti-scouribility value (AS) for RD, RLD and RSAD. Figure 2 shows that AS increased with an increase in RD, RLD and RSAD respectively. The relationship among AS and R, RLD and RSAD for different parameter is given in Table 1 and equation-5. Before the present study, some other similar studies investigating the influence of plant roots on soil anti-scouribility had been conducted. According to Li et al. (1990) and Wu et al. (2000), soil anti-scouribility is a function of the number of roots less than 1 mm in diameter per unit of soil volume. Meanwhile, Mamo and Bubenzer (2001a, 2001b) established a relationship between soil anti-erodibility and root length density. The calculations in these previous studies (either root number or root length) have some advantages for understanding the effects of roots on soil anti-scouribility or anti-erodibility. However, there are some disadvantages. For example, root diameters, even those of roots less than 1 mm in diameter, varied greatly for different vegetations and have different impact on soil anti-scouribility. So, it will be not precise if the intensified soil anti-scouribility effect of the roots is measured only with the number of roots less than 1 mm in diameter per unit of soil volume. Meanwhile, many researchers (Ghidey and Alberts 1997) have pointed out that the increased soil anti-scouribility is due to root enlacing and the adherence of root exudates to soil particles. The roles of both enlacing and adhering are related to the soil-contacting area of the roots. The concept of RSAD can correctly describe the soil-contacting area of the roots. A higher RSAD indicates a larger area of contact between the roots and the soil and more rhizospheres.

According to Reid et al. (1980) and Habib et al. (1990), soil aggregate stability increases because soil particles are enlaced and cohered by roots in rhizospheres. Therefore, the soilanti-scouribility increases.

Thus, it is reasonable to use the RSAD to calculate the value of AS through the equations (equation-5) established in the present study. After analysis in Origin platform following exponential equation (exuation-5) is set with different values of parameters (Table-1) for RD, RLD and RSAD.

$$\Delta AS = Y_o + A_1 \exp(x/t_1) + A_2 \exp(x/t_2) + A_3 \exp(x/t_3)$$ ....(5)

Parameters	RD	RLD	RSAD
Y_o	10.07548	10.25888	12.65134
A_1	-3.37055	-8.11837	-2.06437
t_1	-2.48883	-1.93043	-0.15205
A_2	-3.37055	-8.11837	-4.02216
t_2	-2.48912	-1.93043	-3.62438
A_3	-3.37055	-8.11837	-3.5681
t_3	-2.4890	-1.93043	-0.15183
R^2	0.901	0.902	0.981

Table 1 *Equation expressing the correlations among RD, RLD and RSDA with AS.*

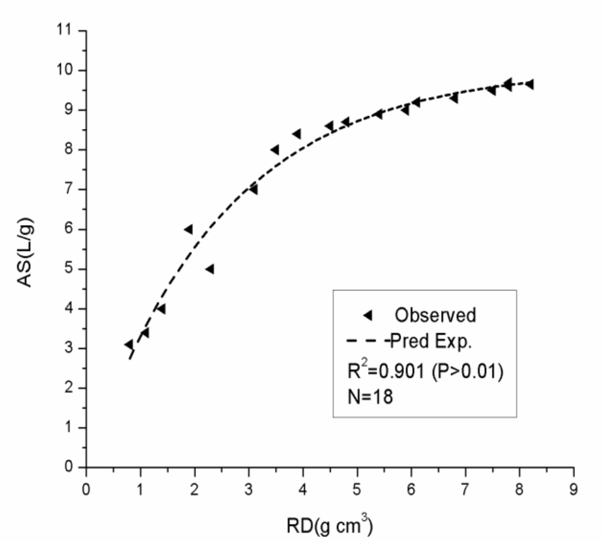

Fig-2 (a) *relationships between intensified soil anti-scourbility (AS) and root density (RD)*

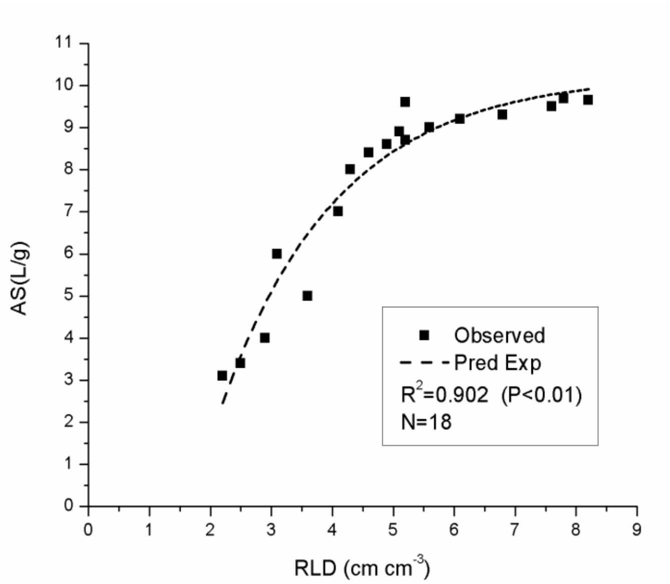

Fig-2 (b) *relationships between intensified soil anti-scourbility (AS) and root length density (RLD)*

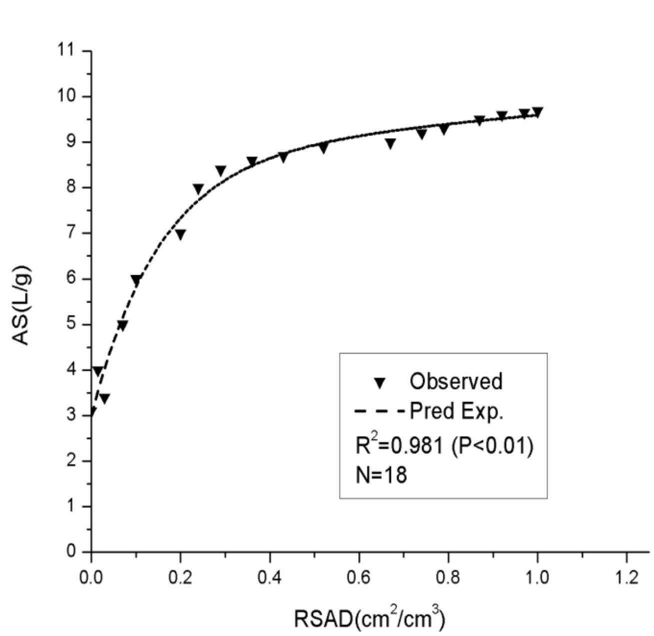

Fig-2 (c) *relationships between intensified soil anti-scourbility (AS) and root surface area density (RSAD)*

Conclusion

Roots play an important role in increasing the topsoil resistance against erosion by concentrated flow. The soil anti-scouribility (AS) increased as RD, RLD and RSAD increased. The effect of plant roots on intensifying soil anti-scouribility could be expressed by an exponential growth function and the AS increased with an increase in RSAD as well as RD and RLD. The results of the present study provide erosion researchers with important and useful information for understanding the effects of the roots parameter of vegetation on erosion mechanisms. The relationship among RSAD, RD, and RLD and AS can be used in the erosion models for the prediction of soil erosion.

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